



Matharu, G. S., Nandra, R. S., Berryman, F., Judge, A., Pynsent, P. B., & Dunlop, D. J. (2017). Risk factors for failure of the 36 mm metal-on-metal Pinnacle total hip arthroplasty system: a retrospective single-centre cohort study. *Bone and Joint Journal*, 99-B(5), 592-600.
<https://doi.org/10.1302/0301-620x.99b5.bjj-2016-1232.r1>

Publisher's PDF, also known as Version of record

License (if available):
CC BY

Link to published version (if available):
[10.1302/0301-620x.99b5.bjj-2016-1232.r1](https://doi.org/10.1302/0301-620x.99b5.bjj-2016-1232.r1)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the final published version of the article (version of record). It first appeared online via SBJS at <https://online.boneandjoint.org.uk/doi/full/10.1302/0301-620X.99B5.BJJ-2016-1232.R1> . Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

■ HIP

Risk factors for failure of the 36 mm metal-on-metal Pinnacle total hip arthroplasty system

A RETROSPECTIVE SINGLE-CENTRE COHORT STUDY

G. S. Matharu,
R. S. Nandra,
F. Berryman,
A. Judge,
P. B. Pynsent,
D. J. Dunlop

From The Royal Orthopaedic Hospital, Birmingham, United Kingdom

■ G. S. Matharu, BSc (Hons), MRCS, MRes, Clinical Research Fellow, The Royal Orthopaedic Hospital, Birmingham, B31 2AP, UK and NDORMS University of Oxford, Oxford, OX3 7LD, UK.

■ R. S. Nandra, BSc, MRCS, Academic Clinical Fellow in Trauma and Orthopaedics
■ F. Berryman, BSc (Hons), PhD, Clinical Scientist
■ D. J. Dunlop, FRCS (Tr&Orth), Consultant Orthopaedic Surgeon
The Royal Orthopaedic Hospital, Birmingham, B31 2AP, UK.

■ A. Judge, BSc, MSc, PhD, Senior Statistician, MRC Lifecourse Epidemiology Unit Southampton General Hospital, University of Southampton, Southampton, SO16 6YD, UK and NDORMS University of Oxford, Oxford, OX3 7LD, UK.

■ P. B. Pynsent, PhD, Honorary Senior Research Fellow School of Clinical and Experimental Medicine, University of Birmingham, B15 2TT, UK.

Correspondence should be sent to G. S. Matharu; email: gsm@doctors.org.uk

©2017 Matharu et al
doi:10.1302/0301-620X.99B5.
BJJ-2016-1232.R1 \$2.00

Bone Joint J
2017;99-B:592–600.
Received 29 November 2016;
Accepted after revision 30
December 2016

Aims

To determine ten-year failure rates following 36 mm metal-on-metal (MoM) Pinnacle total hip arthroplasty (THA), and identify predictors of failure.

Patients and Methods

We retrospectively assessed a single-centre cohort of 569 primary 36 mm MoM Pinnacle THAs (all Corail stems) followed up since 2012 according to Medicines and Healthcare Products Regulation Agency recommendations. All-cause failure rates (all-cause revision, and non-revised cross-sectional imaging failures) were calculated, with predictors for failure identified using multivariable Cox regression.

Results

Failure occurred in 97 hips (17.0%). The ten-year cumulative failure rate was 27.1% (95% confidence interval (CI) 21.6 to 33.7). Primary implantation from 2006 onwards (hazard ratio (HR) 4.30; 95% CI 1.82 to 10.1; $p = 0.001$) and bilateral MoM hip arthroplasty (HR 1.59; 95% CI 1.03 to 2.46; $p = 0.037$) predicted failure. The effect of implantation year on failure varied over time. From four years onwards following surgery, hips implanted since 2006 had significantly higher failure rates (eight years 28.3%; 95% CI 23.1 to 34.5) compared with hips implanted before 2006 (eight years 6.3%; 95% CI 2.4 to 15.8) (HR 15.2; 95% CI 2.11 to 110.4; $p = 0.007$).

Conclusion

We observed that 36 mm MoM Pinnacle THAs have an unacceptably high ten-year failure rate, especially if implanted from 2006 onwards or in bilateral MoM hip patients. Our findings regarding implantation year and failure support recent concerns about the device manufacturing process. We recommend all patients undergoing implantation since 2006 and those with bilateral MoM hips undergo regular investigation, regardless of symptoms.

Cite this article: *Bone Joint J* 2017;99-B:592–600.

Adverse reactions to metal debris (ARMD) have contributed to the high failure rates observed with stemmed metal-on-metal total hip arthroplasties (MoM THAs).^{1–5} These implants are no longer used and patients with these devices currently require regular surveillance.^{6–8} The Medical and Healthcare Products Regulatory Agency (MHRA) recommends that all patients with stemmed MoM THAs and a 36 mm or larger diameter femoral head undergo annual review, which includes measurement of blood metal ions with or without cross-sectional imaging.⁶

The 36 mm MoM Pinnacle THA system (DePuy, Leeds, United Kingdom) was commonly implanted worldwide.^{4,9–11} Although this design has not performed as poorly as other MoM THAs, registries have still observed high ten-year cumulative revision rates of up to 14.6%.^{4,11} A

number of large single-centre cohort studies examining the 36 mm MoM Pinnacle THA system have also confirmed these high failure rates.^{10,12–14} Langton et al¹⁰ recently identified new predictors of revision in 489 MoM Pinnacle THAs with a 36 mm bearing, namely implantation from 2006 onwards, bilateral MoM hip implants, and small Pinnacle liners. Furthermore, explant analysis at their national retrieval centre demonstrated that a number of Pinnacle implants were manufactured out of their intended specification.¹⁰ However, a subsequent review of the 36 mm MoM Pinnacle THA system within the National Joint Registry (NJR) for England and Wales did not observe a higher revision rate for the identified batch numbers compared with others.¹⁵

Given the potential implications of the findings reported by Langton et al¹⁰ on follow-up

Table I. Demographic details of the patient cohort

Covariate		569 hips in 504 patients, n (%)
Gender	Female	331 (58.2)
	Male	238 (41.8)
Age at primary (yrs)	Mean (range)	60.4 (19.8 to 88.0)
Laterality	Unilateral MoM hips	425 (74.7)
	Bilateral MoM hips*	144 (25.3)
Primary (yr)	2004	24 (4.2)
	2005	55 (9.7)
	2006	63 (11.1)
	2007	125 (22.0)
	2008	175 (30.8)
	2009	113 (19.9)
	2010	14 (2.5)
	Pre-2006	79 (13.9)
	2006 onwards	490 (86.1)
Diagnosis	Primary osteoarthritis	524 (92.1)
	Other	45 (7.9)
Surgeon grade	Consultant	550 (96.7)
	Other	19 (3.3)
Surgeon volume	≥ 50 cases (3 surgeons)	431 (75.8)
	< 50 cases (21 surgeons)	138 (24.3)
Surgical approach	Posterior	531 (93.3)
	Anterolateral	38 (6.7)
Liner size (mm)	Median (range)	54 (50 to 66)
	50 to 52	273 (48.0)
	54	134 (23.6)
	56 to 66	162 (28.5)
Femoral head offset	Median (range)	5.0 (-2.0 to 12.0)

*includes 65 bilateral patients (130 hips) with both implants in each patient included in this study, and 14 further patients (14 hips) with unilateral 36 mm MoM Pinnacle total hip arthroplasties included in this study with these patients also having another MoM hip design (36 mm or larger diameter femoral head) on the contralateral side MoM, metal-on-metal

regimens for patients with 36 mm MoM Pinnacle THAs, it is important for the newly identified risk factors to be assessed in external cohorts. We previously reported the medium-term outcomes of the 36 mm MoM Pinnacle THA system at our specialist centre,¹² which represents the second largest study of this particular device.^{9,10,13,14} The failure rate at eight years (11.1%) was unacceptably high in our initial study with many revisions performed for ARMD.¹² However, risk factors for implant failure were not formally assessed in our previous study or in most other reports.^{9,12,14,16}

We aimed to determine the cumulative all-cause failure rate at ten years following implantation of the 36 mm MoM Pinnacle THA system and identify risk factors for failure, with specific focus on the newly identified predictors.¹⁰

Patients and Methods

This retrospective single-centre cohort study included patients treated with a primary MoM Pinnacle THA implanted between 2004 and 2010. This study was registered with the hospital board of our institution; however, ethical approval was not required as patients were assessed according to published regulatory authority guidance.⁶ All patients received a cementless Corail femoral stem (DePuy).

For the present study only hips receiving a 36 mm diameter Articul/eze femoral head (DePuy) were included (14 hips with 28 mm diameter femoral heads excluded). There were 569 primary 36 mm MoM Pinnacle THAs (504 patients) eligible for study inclusion (Table I). These patients have been reported on previously, with information regarding the implants used, surgical procedure, patient follow-up, and blood metal ion analysis described in detail.^{12,17}

Patient follow-up. In 2012, the institution's routine follow-up of patients with the 36 mm MoM Pinnacle THA system was adapted according to recommendations from the MHRA.⁶ All patients were recalled for clinical assessment, which was performed by a combination of senior (consultant) hip surgeons and specialist arthroplasty advanced nurse practitioners in dedicated MoM hip clinics. This clinical assessment included history, examination, anteroposterior pelvic radiographs, blood metal ion sampling,¹⁷ and completion of the Oxford Hip Score (OHS) questionnaire.¹⁸ The OHS is scored on a scale of 0 to 48 points (0, worst possible joint; 48, healthy joint).¹⁹

All symptomatic hips underwent cross-sectional imaging, with asymptomatic hips undergoing cross-sectional imaging if blood metal ion concentrations were above 7 µg/l (MHRA upper-limit).⁶ The institution's cross-sectional imaging protocol has previously been described.^{17,20} Briefly,

this protocol recommends ultrasound for symptomatic patients and metal artifact reduction sequence magnetic resonance imaging (MARS-MRI) for asymptomatic patients. If MARS-MRI was contraindicated then ultrasound was performed. Patients were considered to be symptomatic if when questioned they complained of ipsilateral groin or thigh pain, and/or had experienced episodes of hip squeaking, clicking, grating, locking, clunking, other noises, or instability (and/or these could be elicited during clinical examination). Although no specific OHS threshold was used to distinguish symptomatic patients from asymptomatic individuals, symptomatic patients typically had an OHS of less than 34 of 48 (which represents a fair or poor score; median OHS in symptomatic patients was 30 of 48).¹⁹

All subsequent patient follow-up was dependent on the outcome of the initial assessment. Patients with normal investigations were reviewed annually. Patients with abnormal investigations not undergoing revision were seen more regularly and underwent repeat investigations, typically every three to six months. Revision surgery was recommended based on the overall results of the clinical assessment, with no single investigation used to make decisions regarding revision. Revision surgery for ARMD was performed in certain asymptomatic patients based on abnormal investigations.

Exposure variables and outcomes of interest. Data for this study were extracted from the institution's prospectively maintained clinical database. Exposure covariates of interest recorded in this database included patient demographics (gender, age, MoM hip laterality and hip diagnosis), and details related to the primary surgery (year of surgery, surgeon grade and volume, approach, acetabular liner size and femoral head offset).

The study outcome of interest was all-cause failure. The definition for failure included revision surgery performed for any indication, and non-revised hips with cross-sectional imaging evidence of ARMD. Patients were considered to have imaging evidence of ARMD if they had a pathological effusion or pseudotumour as previously described.²¹⁻²³ Pathological effusions were diagnosed when the depth of fluid exceeded 15 mm at the anterior joint line on ultrasound²² and the patient had raised blood cobalt concentrations (above 3.57 µg/l as recently described).¹⁷ A pseudotumour was defined as a cystic, solid or mixed mass in continuity with the hip joint but extending beyond the confines of the anatomical joint.^{22,23} Lesions meeting these criteria were diagnosed as pseudotumours regardless of the wall thickness or blood metal ion concentrations. Hips with imaging evidence of ARMD remained under regular surveillance due to clinician and/or patient preference. This included circumstances where patients had decided against revision surgery whilst asymptomatic, or where revision surgery had been recommended but patients were unfit to undergo further surgery.

Revision surgery was defined as removal or exchange of any component implanted at the primary surgery, including

isolated femoral head and acetabular liner exchanges. In all revised cases, the database and hospital records were reviewed to determine the cause of failure. This included review of the pre-revision investigations, the revision operation report, and the results of the microbiological and histopathological analyses performed on intra-operative samples. Hips were considered revised for ARMD if there was intra-operative evidence of pseudotumour, metallosis, synovitis, tissue damage and/or necrosis, combined with histopathological confirmation of ARMD.²³⁻²⁷ If revision surgery had been performed at another centre, the institution was contacted to obtain the relevant data. All arthroplasty surgeons have an individual NJR profile which tracks the outcomes of any THAs they have performed, even when further procedures are undertaken by other individuals at another centre.²⁸ Revisions were identified as having occurred elsewhere when the patient had informed us of such procedures, or if additional revisions had been identified from the primary surgeon's individual NJR profile. All failures up until October 2016 were included in this study. No primary 36 mm MoM Pinnacle THAs were awaiting revision surgery at the time of writing.

Statistical analysis. This was performed using Stata Version 14.2 (Stata Corp., College Station, Texas). The significance level for all analyses was a p-value < 0.05, with 95% confidence intervals (CI) also used. Cumulative implant failure rates following primary 36 mm MoM Pinnacle THA were estimated using the Kaplan-Meier method. Hips that did not fail were censored on the date of last clinical follow-up, or on the date of death.

Cox proportional hazards models (univariable and multivariable) were used to assess the effects of the predictor variables on time to failure. For continuous predictors, fractional polynomial regression modelling was used to assess the assumption of linearity with outcome, with data grouped if the assumption was not satisfied. Proportional hazards assumptions for each predictor were assessed using Schoenfeld's residuals.²⁹ If these assumptions were not satisfied, the hazard ratios (HR) were examined in various follow-up time groups, with breaks placed at the points of divergence from proportionality. Likelihood ratio tests were used to assess evidence of two-way interactions between gender and other predictors, including acetabular liner size. The final multivariable model was developed using stepwise backward selection methods. In this automated process all potential predictors are initially included in the model with p-values for removing ($p \geq 0.20$) and including ($p < 0.10$) predictors in the final multivariable model set. The analytical software subsequently compares different statistical models and sequentially removes any variables that do not significantly affect the model fit until the final model with the best fit is identified. As a sensitivity analysis, the models were also repeated with all-cause revision surgery used as the endpoint.

As the effect of year on primary 36 mm MoM Pinnacle THA implantation (pre-2006 *versus* 2006 onwards) on

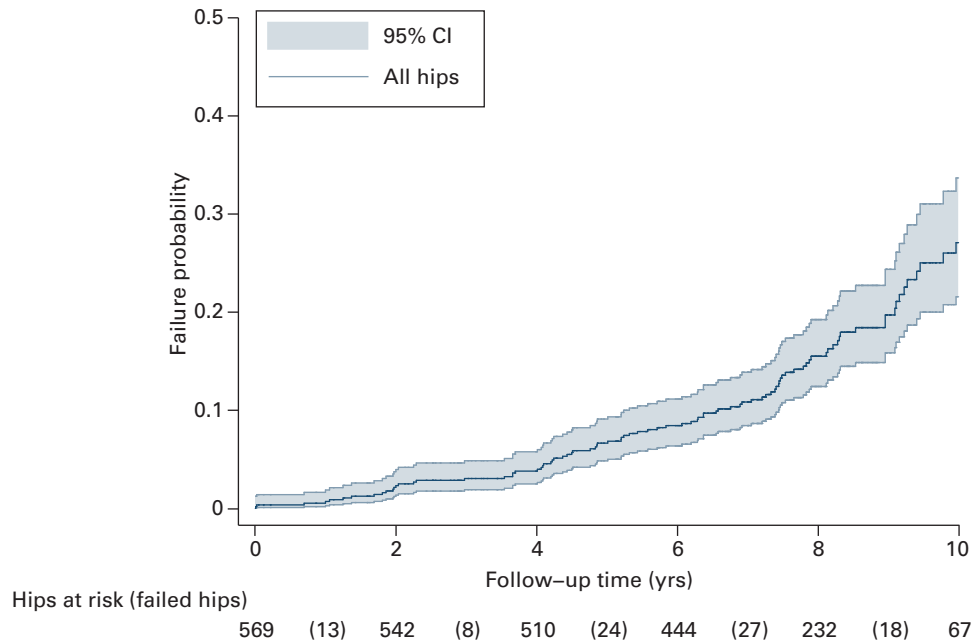


Fig. 1

Graph showing cumulative all-cause failure rate following 36 mm primary metal-on-metal Pinnacle total hip arthroplasty at up to ten years. Shaded area represents the respective upper and lower limits of the 95% confidence intervals (CIs). Risk table indicates the number of hips at risk at two year intervals, with the corresponding number in brackets detailing the number of failed hips during each two-year interval. Seven failures occurred after ten-years follow-up and therefore are not included in the risk table.

failure rate was being assessed, further analyses were performed to more accurately examine these relationships. Previous work highlighted potential variations in the 36 mm MoM Pinnacle THA system manufacturing process from 2006 onwards.¹⁰ Given that 2006 was the transition year for this potential variation, Cox regression analyses were repeated with all hips implanted in 2006 excluded. Furthermore, the follow-up time from primary implantation between groups was different with the pre-2006 implantation group having longer follow-up than the 2006 onwards group. To control for this follow-up variability the Cox regression analyses were repeated in a subgroup of hips. This subgroup included all non-failed hips with a minimum of eight years follow-up (with these hips all censored as not failing at eight years) and all failed hips. For this particular analysis, all hips failing before eight years were censored as failures but any hips failing after eight years were censored at eight years as not failing. Follow-up was truncated at eight years because after this time there were fewer hips at risk in the 2006 onwards group.

Results

Failures occurred in 97 hips (17.0%) at a mean time of 6.0 years (0.01 to 12.2) from primary arthroplasty. These failures consisted of 75 all-cause revisions and 22 additional ARMD imaging failures under surveillance. ARMD was the most common indication for failure ($n = 72$; 74.2% of all failures) and for revision surgery ($n = 50$; 66.7% of all

revisions). Non-ARMD revision indications were aseptic loosening ($n = 8$; 10.7%), infection ($n = 6$; 8.0%), dislocation ($n = 5$; 6.7%), and other ($n = 6$; 8.0%). Of the 22 ARMD imaging failures, 20 hips had large cystic ($n = 18$) or mixed ($n = 2$) pseudotumours, with 15 of these patients having blood cobalt concentrations above the 3.57 $\mu\text{g/l}$ threshold.¹⁷ Pseudotumour volumes ranged from 30 cm^3 to 192 cm^3 . The remaining two ARMD imaging failures were pathological effusions. These were cystic collections (volumes between 25 cm^3 and 30 cm^3), with blood cobalt concentrations of 8.1 $\mu\text{g/l}$ and 9.2 $\mu\text{g/l}$ respectively.

There were 23 non-failing hips (4.0%) that died at a mean time of 2.8 years (0.04 to 7.2) from surgery. The remaining 449 hips that did not fail or die were followed up for a mean time of 8.0 years (1.0 to 12.0). The median (interquartile range (IQR)) whole blood cobalt and chromium concentrations in these patients at latest follow-up were 2.36 $\mu\text{g/l}$ (IQR 0.83 to 4.30) and 1.46 $\mu\text{g/l}$ (IQR 0.88 to 2.44), respectively. The median post-operative OHS was 43 of 48 (IQR 33 to 48).

Failure rates. The cumulative ten-year failure rate following primary 36 mm MoM Pinnacle THA was 27.1% (95% CI 21.6 to 33.7; 67 hips remained at risk at ten years) (Fig. 1). The ten-year rate for revision surgery only (i.e. excluding the ARMD imaging failures) was 20.3% (95% CI 15.7% to 26.1%).

Risk factors for failure. Multivariable analysis identified two predictors of failure: bilateral MoM hip arthroplasty

Table II. Univariable and multivariable Cox regression models for identifying risk factors for all-cause failure

Covariate	Univariable hazard ratio (95% CI)	p-value	Multivariable hazard ratio (95% CI)	p-value
Gender				
Female vs male	1.61 (1.03 to 2.50)	0.036*	1.49 (0.94 to 2.37)	0.092
Age at primary (per yr)	1.02 (0.99 to 1.04)	0.142	1.02 (0.99 to 1.05)	0.085
Laterality				
Bilateral vs unilateral	1.60 (1.04 to 2.45)	0.031*	1.59 (1.03 to 2.46)	0.037*
Yr of primary				
2006 onwards vs pre-2006	4.88 (2.09 to 11.4)	< 0.001*	4.30 (1.82 to 10.1)	0.001*
Diagnosis				
Primary osteoarthritis vs other	1.69 (0.69 to 4.17)	0.252	†	†
Surgeon grade				
Consultant vs other	0.44 (0.18 to 1.09)	0.075	0.55 (0.22 to 1.37)	0.199
Surgeon volume				
≥ 50 cases vs < 50 cases	0.74 (0.47 to 1.17)	0.196	†	†
Surgical approach				
Posterior vs anterolateral	0.53 (0.25 to 1.17)	0.115	0.55 (0.24 to 1.24)	0.148
Liner size				
50 mm to 52 mm	1.00 (reference group)		1.00 (reference group)	
54 mm	0.62 (0.36 to 1.06)	0.083	0.66 (0.38 to 1.12)	0.125
56 mm to 66 mm	0.65 (0.39 to 1.08)	0.095	‡	‡
Femoral head offset				
per +3.5 increase	0.80 (0.63 to 1.02)	0.078	0.81 (0.62 to 1.07)	0.138

*statistically significant differences ($p < 0.05$)

†covariate was not eligible for inclusion in the final multivariable model

‡specific subgroup did not meet inclusion criteria for final multivariable model ($p > 0.200$)

CI, confidence interval

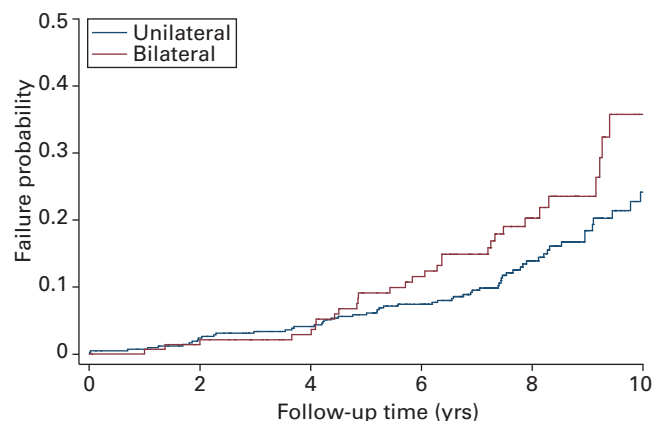


Fig. 2

Graph showing cumulative all-cause failure rates following 36 mm primary metal-on-metal Pinnacle total hip arthroplasty at up to ten-years by implant laterality; 95% confidence intervals have been included in the main text, but are omitted from the figure for clarity.

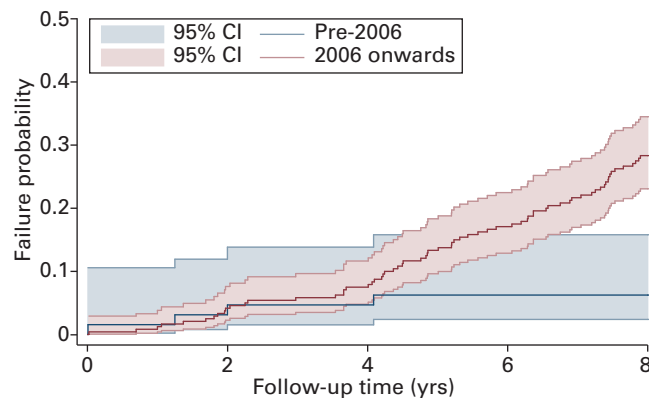


Fig. 3

Graph showing cumulative all-cause failure rates following 36 mm primary metal-on-metal Pinnacle total hip arthroplasty at up to eight years by year of implantation. Shaded area represents the respective upper and lower limits of the 95% confidence intervals (CIs). Model based on a subgroup of 304 hips (72 all-cause failures) with 232 hips at risk at eight years.

(HR 1.59, 95% CI 1.03 to 2.46; $p = 0.037$), and primary hip implantation from 2006 onwards (HR 4.30, 95% CI 1.82 to 10.1; $p = 0.001$) (Table II). The ten-year failure rate was 35.8% (95% CI 24.4% to 50.4%) in bilateral MoM hip patients (all sequential hip implantations) compared with 24.2% (95% CI 18.2% to 31.7%) in unilateral patients (Fig. 2).

After excluding hips implanted in 2006 ($n = 63$), primary implantation from 2007 onwards remained a predictor of failure compared with hips implanted before 2006 (HR 4.55, 95% CI 1.84 to 11.2; $p = 0.001$). Further analysis

regarding year of implantation was performed on 304 hips (72 failures). This demonstrated that the effect of year of primary implantation on failure rates varied over time. Year of implantation did not affect failure rates within four years of arthroplasty (HR 1.60, 95% CI 0.47 to 5.44; $p = 0.450$), with four-year failure rates of 7.5% (95% CI 4.8% to 11.6%) and 4.7% (95% CI 1.5% to 13.8%) for hips implanted from 2006 onwards and before 2006 respectively (Fig. 3). Between four years and eight years from primary surgery, hips implanted from 2006 onwards had a significantly higher failure rate (at eight years 28.3%,

95% CI 23.1% to 34.5%) compared with hips implanted before 2006 (at eight years 6.3%, 95% CI 2.4% to 15.8%) (HR 15.2, 95% CI 2.11 to 110.4; $p = 0.007$).

Small liner size did not predict failure. Likelihood ratio testing demonstrated a borderline significant interaction between liner size and gender ($p = 0.0493$). The effect of liner size on failure rates was further examined in men and women separately, which confirmed that liner size did not predict failure in either gender.

Risk factors for revision surgery were also examined. The results from the multivariable analysis were the same as for all-cause failure, with bilateral MoM hip arthroplasty (HR 2.02, 95% CI 1.25 to 3.25; $p = 0.004$), and primary hip implantation from 2006 onwards (HR 2.64, 95% CI 1.12 to 6.20; $p = 0.026$) identified as predictors of revision.

Discussion

The 36 mm MoM Pinnacle THA system was one of the most commonly implanted MoM THAs worldwide.^{4,9-11} Recently, Langton et al¹⁰ identified new risk factors for implant failure, which raised serious questions regarding the device manufacturing process since 2006. The clinical implications of the concerns raised by Langton et al¹⁰ regarding potential errors in the manufacturing tolerances are significant; therefore it is important for other institutions, such as ours, to publish their data. The present study represents one of the largest non-registry cohorts of 36 mm MoM Pinnacle THA patients, and has the longest follow-up period.^{9,10,13,14} High ten-year failure rates were observed with the 36 mm MoM Pinnacle THA system, with ARMD representing the most common indication for failure. However, the greatest risk of device failure occurred in hips implanted from 2006 onwards, and in bilateral MoM hip arthroplasty patients. Our findings therefore support the newly identified risk factors for 36 mm MoM Pinnacle THA failure.¹⁰

The unacceptably high failure rates of stemmed MoM THAs are undisputed, with these devices no longer implanted worldwide.¹⁴ Whilst some MoM THAs had very high short-term failure rates, such as the ASR XL (DePuy), the 36 mm MoM Pinnacle THA system did not perform as poorly according to registry data.^{4,11} However, registries have recognised limitations, including the potential to under-report revisions and the inability to account for non-revised imaging failures.^{30,31} We observed high rates of failure (27.1%) and revision surgery (20.3%) at ten years following primary 36 mm MoM Pinnacle THA. Our revision rate was comparable with recent studies from Langton et al¹⁰ ($n = 489$) and Lainiala et al¹³ ($n = 430$) who reported rates of up to 16.4% at nine years. However, we considered it important to include non-revised patients with imaging evidence of ARMD as failures. This more accurately estimates the scale of the problem, given that the threshold for performing revision may differ between surgeons, and patients with failing implants may be unfit or

unwilling to undergo further surgery. Indeed, all of the non-revised patients with imaging failures identified in our previous report have now undergone revision surgery.¹²

It is suspected that surveillance bias introduced from regular patient follow-up^{6,8} has contributed to the high rates of failure and revision reported by this and other studies for the 36 mm MoM Pinnacle THA system.^{10,12-14} However, the failure rate continues to increase steadily up to ten years (Fig. 1) rather than plateau as one may expect following early revision of poorly performing implants. Perhaps more concerning are the recent observations that in MoM hip resurfacing patients, failure rates continue to increase up to 15 years from implantation.³² Stemmed MoM THAs have higher failure rates compared with hip resurfacings, even when bearing surfaces are identical.^{2,4,11,33} Therefore we suspect many more MoM THAs will require revision in the second decade following implantation. This itself is likely to be problematic given that the outcomes reported following MoM hip revision surgery for ARMD have also been poor.^{34,35}

The most important predictor of failure in our cohort was primary implantation from 2006 onwards. However, hips implanted from 2006 onwards only had a significantly higher failure rate between four years and eight years from primary surgery (Fig. 3), with most failures due to ARMD. This reflects the time at which ARMD failures can be expected to occur.^{10,36} Langton et al¹⁰ similarly identified an increased risk of failure in 36 mm MoM Pinnacle THAs implanted from 2006 onwards. Furthermore, the findings from their national implant retrieval centre, which receives many failed prostheses from numerous institutions, demonstrated that 36 mm MoM Pinnacle THAs manufactured from 2006 onwards were increasingly likely to have lower clearance values than intended by the manufacturer.¹⁰ Low clearance between the femoral head and acetabular liner can lead to edge loading, excessive bearing wear, and ultimately implant failure.³⁷ Furthermore, low clearance may contribute to higher friction at the bearing surface and/or taper junction, which can also result in increased wear and implant failure.^{38,39}

In light of the findings from two large clinical cohorts comprising over 1000 36 mm MoM Pinnacle THA systems and the results of the retrieval analysis on failed implants from a wide geographical area,¹⁰ we conclude that the potential variations in manufacturing tolerances are unlikely to be confined to a specific batch of implants and/or region of the country. Our findings regarding implantation year and failure therefore support recent concerns about the 36 mm MoM Pinnacle THA system manufacturing process since 2006.¹⁰ Although large registry cohorts would help support these new observations, registries have recognised limitations.^{30,31} In addition, the high failure rates associated with MoM hip arthroplasties were identified by others^{5,40} some time before registries detected the problem.^{11,41} Therefore, there may be a delay before registries identify a higher failure rate in 36 mm MoM Pinnacle THAs implanted since 2006.

Some regulatory authorities consider patients with bilateral MoM hip arthroplasties to be at increased risk of failure,^{8,42} given that these patients can develop bilateral ARMD.⁴³⁻⁴⁵ Bilateral failures seem to occur in patients undergoing sequential hip implantation, with suggestion that a delayed type IV immune reaction is responsible.⁴³⁻⁴⁵ We observed patients with bilateral MoM hip arthroplasties to be at high risk of implant failure, which confirms recent findings in another 36 mm MoM Pinnacle THA cohort¹⁰ but is contrary to that reported in large hip resurfacing cohorts.³² Bilateral MoM THAs may have a higher risk of failure compared with bilateral hip resurfacings given recent observations that metal debris generated from taper junctions can be more immunogenic than that from bearing surfaces.⁴⁶ Further research is therefore needed regarding the pathogenesis of failure in bilateral MoM hip arthroplasties. However, we consider 36 mm MoM Pinnacle THA patients with bilateral MoM hips at high risk of failure and therefore recommend these patients undergo regular surveillance.

In this study, small acetabular liner size did not predict failure, both in the whole cohort and when subdivided by gender. Although Langton et al¹⁰ recently reported small liner size as a predictor of failure when assessed as a categorical variable, small liner size was not a significant predictor in their all-cause revision model. Assessing liner size in MoM THAs is difficult given it is closely related to gender, much like the complex relationship observed between gender and femoral head size in hip resurfacing.³² Assessment in 36 mm MoM Pinnacle THAs is further complicated by there being nine different liner sizes available (50 mm to 66 mm), with the smallest size not introduced until 2008 (hence liner size was grouped in this study). Although we do not feel that 36 mm MoM Pinnacle THA patients require risk stratification for clinical surveillance based on liner size, it is recommended that future studies assessing this implant explore the relationship between liner size and implant failure.

Given that we have now validated the risk factors for failure of the 36 mm MoM Pinnacle THA system initially reported by Langton et al,¹⁰ it is important that the many patients worldwide with these implants *in situ* are managed appropriately. Current MHRA follow-up recommendations suggest that asymptomatic patients with non-ASR stemmed MoM THRs and a 36 mm or larger diameter femoral head only require cross-sectional imaging if blood metal ion concentrations are above 7 µg/l and rising on repeat testing.⁶ We suggest this follow-up guidance should be modified so that all 36 mm MoM Pinnacle THAs implanted since 2006 and those with bilateral MoM hips should also undergo cross-sectional imaging, regardless of symptoms. However, this additional follow-up is likely to be very costly and resource intensive,⁴⁷ given that most patients with these devices are asymptomatic^{10,12,13} and most of these prostheses were implanted from 2006 onwards.^{4,11}

The main study limitation is that hips revised at this institution did not undergo explant analysis. Therefore, unlike in the recent study by Langton et al,¹⁰ we cannot confirm whether or not the specific Pinnacle implants removed were manufactured outside of their intended specification. Although attempts were made to identify all revisions, including using NJR surgeon data, it is possible some hips were revised elsewhere and not reported to the NJR; therefore, our failure rates represent the best-case scenario. The formal radiographic analysis from the initial study¹² was not updated here; therefore it is acknowledged that some non-revised patients may have radiological evidence of implant failure which may eventually require revision. Despite assessing a large cohort at extended follow-up, it is recognised this represents a selected population in a specific geographical area. Although registries have limitations,^{30,31} analysis of a large unselected registry cohort would complement the single-centre cohort studies performed by ourselves and others.¹⁰ A further limitation is the lack of a control group of patients with other MoM THA designs. Such a comparator group would allow a more accurate assessment of the extent of surveillance bias on implant failure rates in more recent years.⁶⁻⁸ Finally, although our survival analysis was robust, there is a potential for residual confounding.

In conclusion, this large cohort study has demonstrated that the 36 mm MoM Pinnacle THA system has an unacceptably high ten-year failure rate. The failure rate was especially high in hips implanted from 2006 onwards and in bilateral MoM hip arthroplasty patients. Our findings regarding year of implantation and failure rates support recent serious concerns about previously unrecognised changes in the device manufacturing process.¹⁰ We recommend that all patients with 36 mm MoM Pinnacle THA systems implanted since 2006 and those with bilateral MoM hips undergo regular investigation, including blood metal ions and cross-sectional imaging, regardless of symptoms.



Take home message:

- An unacceptably high ten-year failure rate was observed in 36 mm MoM Pinnacle THA systems, especially in those implanted from 2006 onwards, and in bilateral MoM hip patients.
- All patients with these devices implanted since 2006, and those with bilateral MoM hips should undergo regular investigation with blood metal ions and cross-sectional imaging, regardless of symptoms.

Author contributions:

G. S. Matharu: Study design, Data collection, Data analysis, Manuscript draft and revision.
 R. S. Nandra: Study design, Data collection, Manuscript revision and approval.
 F. Berryman: Study design, Data collection, Manuscript revision and approval.
 A. Judge: Study design, Data analysis, Manuscript revision and approval.
 P. B. Pynsent: Study design, Data analysis, Manuscript revision and approval.
 D. J. Dunlop: Study design, Performed surgeries, Manuscript revision and approval.

The authors would like to thank Arthritis Research UK, and The Royal Orthopaedic Hospital Hip Research and Education Charitable Fund who have both provided one of the authors with funding to undertake this research.

The author or one or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or

indirectly to the subject of this article. In addition, benefits have been or will be directed to a research fund, foundation, educational institution, or other non-profit organisation with which one or more of the authors are associated.

This is an open-access article distributed under the terms of the Creative Commons (CC-BY) license, which permits copying and redistributing the material in any medium or format, remixing, transforming and building upon the material for any purpose, even commercially, provided the original author and source are credited, and changes made are indicated. This may be done in a reasonable manner, but not in any way that suggests the licensor endorses you or your use.

This article was primary edited by G. Scott.

References

1. Smith AJ, Dieppe P, Vernon K, et al. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet* 2012;379:1199–1204.
2. Langton DJ, Jameson SS, Joyce TJ, et al. Accelerating failure rate of the ASR total hip replacement. *J Bone Joint Surg [Br]* 2011;93-B:1011–1016.
3. Bolland BJ, Culliford DJ, Langton DJ, et al. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. *J Bone Joint Surg [Br]* 2011;93-B:608–615.
4. No authors listed. Australian Orthopaedic Association National Joint Replacement Registry: Hip and Knee Arthroplasty. Annual Report 2015. <https://aoanjrr.sahmri.com/annual-reports-2016> (date last accessed 20 February 2017).
5. Langton DJ, Jameson SS, Joyce TJ, et al. Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: A consequence of excess wear. *J Bone Joint Surg [Br]* 2010;92-B:38–46.
6. No authors listed. Medical and Healthcare products Regulatory Agency (MHRA). Medical Device Alert: all metal-on-metal (MoM) hip replacements. MDA/2012/036. <http://www.mhra.gov.uk/> (date last accessed 20 February 2017).
7. No authors listed. European Federation of National Associations of Orthopaedics and Traumatology. Consensus statement "Current evidence on the management of metal-on-metal bearings." https://www.efort.org/wp-content/uploads/2013/10/2012_05_10_MoM_Consensus_statement1.pdf (date last accessed 20 February 2017).
8. No authors listed. U.S. Food and Drug Administration. Medical Devices. Metal-on-Metal Hip Implants. Information for Orthopaedic Surgeons. <http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/ImplantsandProsthetics/Metalon-MetalHipImplants/ucm241667.htm> (date last accessed 20 February 2017).
9. Barrett WP, Kindsfater KA, Lesko JP. Large-diameter modular metal-on-metal total hip arthroplasty: incidence of revision for adverse reaction to metallic debris. *J Arthroplasty* 2012;27:976–983.
10. Langton DJ, Sidaginamale RP, Avery P, et al. Retrospective cohort study of the performance of the Pinnacle metal on metal (MoM) total hip replacement: a single-centre investigation in combination with the findings of a national retrieval centre. *BMJ Open* 2016;6:007847.
11. No authors listed. National Joint Registry. 13th Annual Report 2016. <http://www.njrcentre.org.uk/njrcentre/Portals/0/Documents/England/Reports/13th%20Annual%20Report/07950%20NJR%20Annual%20Report%202016%20ONLINE%20REPORT.pdf> (date last accessed 20 February 2017).
12. Matharu GS, Theivendran K, Pynsent PB, et al. Outcomes of a metal-on-metal total hip replacement system. *Ann R Coll Surg Engl* 2014;96:530–535.
13. Lainiala O, Eskelinen A, Elo P, et al. Adverse reaction to metal debris is more common in patients following MoM total hip replacement with a 36 mm femoral head than previously thought: results from a modern MoM follow-up programme. *Bone Joint J* 2014;96-B:1610–1617.
14. Bernasek TL, Polikandriotis JA, Levering MF, et al. Five- to ten-year outcomes for modular metal-on-metal total hip arthroplasty. *J Arthroplasty* 2013;28:1231–1234.
15. No authors listed. BOA/BHS joint statement. BMJ: Metal hip replacements implanted since 2006 more prone to failure. 2016. <http://www.boa.ac.uk/latest-news/11277/> (date last accessed 20 February 2017).
16. Liudahl AA, Liu SS, Goetz DD, Mahoney CR, Callaghan JJ. Metal on metal total hip arthroplasty using modular acetabular shells. *J Arthroplasty* 2013;28:867–871.
17. Matharu GS, Berryman F, Brash L, et al. The effectiveness of blood metal ions in identifying patients with unilateral Birmingham Hip Resurfacing and Corail-Pinnacle metal-on-metal hip implants at risk of adverse reactions to metal debris. *J Bone Joint Surg [Am]* 2016;98:617–626.
18. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. *J Bone Joint Surg [Br]* 1996;78-B:185–190.
19. Murray DW, Fitzpatrick R, Rogers K, et al. The use of the Oxford hip and knee scores. *J Bone Joint Surg [Br]* 2007;89-B:1010–1014.
20. Matharu GS, Berryman F, Brash L, et al. Can blood metal ion levels be used to identify patients with bilateral Birmingham Hip Resurfacings who are at risk of adverse reactions to metal debris? *Bone Joint J* 2016;98-B:1455–1462.
21. Hart AJ, Satchithananda K, Liddle AD, et al. Pseudotumors in association with well-functioning metal-on-metal hip prostheses: a case-control study using three-dimensional computed tomography and magnetic resonance imaging. *J Bone Joint Surg [Am]* 2012;94-A:317–325.
22. Low AK, Matharu GS, Ostlere SJ, Murray DW, Pandit HG. How should we follow-up asymptomatic metal-on-metal hip resurfacing patients? A prospective longitudinal cohort study. *J Arthroplasty* 2016;31:146–151.
23. Matharu GS, Mansour R, Dada O, et al. Which imaging modality is most effective for identifying pseudotumours in metal-on-metal hip resurfacings requiring revision: ultrasound or MARS-MRI or both? *Bone Joint J* 2016;98-B:40–48.
24. Lainiala O, Elo P, Reito A, et al. Comparison of extracapsular pseudotumors seen in magnetic resonance imaging and in revision surgery of 167 failed metal-on-metal hip replacements. *Acta Orthop* 2014;85:474–479.
25. Willert HG, Buchhorn GH, Fayyazi A, et al. Metal-on-metal bearings and hypersensitivity in patients with artificial hip joints. A clinical and histomorphological study. *J Bone Joint Surg [Am]* 2005;87-A:28–36.
26. Campbell P, Ebrahmdadeh E, Nelson S, et al. Histological features of pseudotumor-like tissues from metal-on-metal hips. *Clin Orthop Relat Res* 2010;468:2321–2327.
27. Grammatopoulos G, Pandit H, Kamali A, et al. The correlation of wear with histological features after failed hip resurfacing arthroplasty. *J Bone Joint Surg [Am]* 2013;95:81.
28. No authors listed. National Joint Registry Clinician Feedback. <http://www.njrclinicianfeedback.org.uk/Login.aspx?ReturnUrl=%2f> (date last accessed 03 April 2017).
29. Schoenfeld D. Partial residuals for the proportional hazards regression model. *Biometrika* 1982;69:239–241.
30. Konan S, Haddad FS. Joint Registries: a Ptolemaic model of data interpretation? *Bone Joint J* 2013;95-B:1585–1586.
31. Sabah SA, Henckel J, Cook E, et al. Validation of primary metal-on-metal hip arthroplasties on the National Joint Registry for England, Wales and Northern Ireland using data from the London Implant Retrieval Centre: a study using the NJR dataset. *Bone Joint J* 2015;97-B:10–18.
32. Matharu GS, Judge A, Murray DW, Pandit HG. Prevalence of and risk factors for hip resurfacing revision: a cohort study into the second decade after the operation. *J Bone Joint Surg [Am]* 2016;98:1444–1452.
33. Garbuz DS, Tanzer M, Greidanus NV, Masri BA, Duncan CP. The John Charnley Award: Metal-on-metal hip resurfacing versus large-diameter head metal-on-metal total hip arthroplasty: a randomized clinical trial. *Clin Orthop Relat Res* 2010;468:318–325.
34. Matharu GS, Pynsent PB, Dunlop DJ. Revision of metal-on-metal hip replacements and resurfacings for adverse reaction to metal debris: a systematic review of outcomes. *Hip Int* 2014;24:311–320.
35. Munro JT, Masri BA, Duncan CP, Garbuz DS. High complication rate after revision of large-head metal-on-metal total hip arthroplasty. *Clin Orthop Relat Res* 2014;472:523–528.
36. Lainiala O, Reito A, Elo P, et al. Revision of metal-on-metal hip prostheses results in marked reduction of blood cobalt and chromium ion concentrations. *Clin Orthop Relat Res* 2015;473:2305–2313.
37. Underwood RJ, Zografos A, Sayles RS, Hart A, Cann P. Edge loading in metal-on-metal hips: low clearance is a new risk factor. *Proc Inst Mech Eng H* 2012;226:217–226.
38. Liu F, Chen Z, Gu Y, et al. Deformation of the Durom acetabular component and its impact on tribology in a cadaveric model—a simulator study. *PLoS One* 2012;7:45786.
39. Daniel J, Ziaee H, Kamali A, Pradhan C, McMinn D. What are the risks accompanying the reduced wear benefit of low-clearance hip resurfacing? *Clin Orthop Relat Res* 2012;470:2800–2809.
40. Pandit H, Glynn-Jones S, McLardy-Smith P, et al. Pseudotumours associated with metal-on-metal hip resurfacings. *J Bone Joint Surg [Br]* 2008;90-B:847–851.
41. No authors listed. Medical and Healthcare products Regulatory Agency (MHRA). Medical Device Alert: ASR hip replacement implant manufactured by DePuy International Ltd. MDA/2010/069. <http://www.mhra.gov.uk/> (date last accessed 20 February 2017).

- 42. No authors listed.** Health Canada. Government of Canada. Metal-on-Metal Hip Implants - Information for Orthopaedic Surgeons Regarding Patient Management Following Surgery - For Health Professionals. <http://healthycanadians.gc.ca/recall-alert-rappel-avis/hc-sc/2012/15835a-eng.php> (date last accessed 20 February 2017).
- 43. Pandit H, Vlychou M, Whitwell D, et al.** Necrotic granulomatous pseudotumours in bilateral resurfacing hip arthroplasties: evidence for a type IV immune response. *Virchows Arch* 2008;453:529–534.
- 44. Killampalli VV, Reading AD.** Late instability of bilateral metal on metal hip resurfacings due to progressive local tissue effects. *Hip Int* 2009;19:287–291.
- 45. Madanat R, Hussey DK, Donahue GS, et al.** The symmetry of adverse local tissue reactions in patients with bilateral simultaneous and sequential ASR hip replacement. *J Arthroplasty* 2015;30:1794–1798.
- 46. Sidaginamale RP, Joyce TJ, Bowsher JG, et al.** The clinical implications of metal debris release from the taper junctions and bearing surfaces of metal-on-metal hip arthroplasty: joint fluid and blood metal ion concentrations. *Bone Joint J* 2016;98-B:925–933.
- 47. Matharu GS, Mellon SJ, Murray DW, Pandit HG.** Follow-up of metal-on-metal hip arthroplasty patients is currently not evidence based or cost effective. *J Arthroplasty* 2015;30:1317–1323.